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紫胶玉米混农林模式对地表蚂蚁多样性及功能群的影响*

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摘 要 为了揭示紫胶玉米混农林对地表蚂蚁群落多样性及功能群的影响，采用陷阱法调查了云南省绿春县紫胶林、紫胶玉米混农林和玉米旱地 3 种类型样地的地表蚂蚁物种组成、物种多样性、群落结构相似性、指示物种和功能群等。结果显示，紫胶玉米混农林模式具有较高的地表蚂蚁物种数和稀有物种数，与玉米旱地相比，紫胶玉米混农林的蚂蚁物种数增加 41%，稀有物种数增加 85%。紫胶玉米混农林与紫胶林具有更高的蚂蚁多样性，其物种丰富度和 ACE 估值均显著高于玉米旱地，而紫胶玉米混农林的多度显著高于紫胶林和玉米旱地。地表蚂蚁物种组合在 3 种类型样地中有差异，与紫胶林和紫胶玉米混农林相关联的物种与玉米旱地不同。3 种样地的指示物种不同，玉米旱地的指示种为扁平虹臭蚁和伊大头蚁，紫胶玉米混农林为凹头臭蚁、西昌刺结蚁和中华小家蚁，紫胶林为费氏盘腹蚁、立毛举腹蚁、阿普特铺道蚁、贝卡盘腹蚁和西氏拟毛蚁。紫胶玉米混农林蚂蚁功能群组成比例介于玉米旱地和紫胶林之间，其中机会主义者(OPP)、从属弓背蚁族(SC)、隐蔽物种(C)及气候特化种(CS)的蚂蚁物种数、多度及比例明显高于玉米旱地。紫胶玉米混农林生境较为复杂，对地表蚂蚁多样性保护具有积极作用，是平衡环境保护和经济可持续发展的较好模式。

关键词 土地利用 紫胶玉米混农林模式 地表蚂蚁 群落组成 生物多样性 指示物种 功能群

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Effects of lac-corn agroforest ecosystem on ground-dwelling ant diversity and functional groups*

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Abstract The ecological consequences of the changes in ecosystem functions caused by land use change have attracted more attention in recent years. However, less study has focused on the relationship between biodiversity and ecosystem function. Agroforest ecosystem is the combination of agriculture and forestry for management purposes. As an important model, agroforestry has vital ecological benefits for land use substantial development. Agroforestry has been considered to support more species survival and higher biodiversity. Lac insects (*Kerria* spp.) as well as their excrement are important resource insects widely used in many fields including food, medicine and military industry. Lac-corn agroforestry ecosystem is popular pattern of lac production in mountain areas of Southwest China where lac production accounts for a good fraction of the income of farmers' households. However, there is less research on the functional groups of arthropods in lac-corn agroforestry. Ants (Hymenoptera: Formicidae) are widely distributed in many terrestrial ecosystems. They can be used as indicator for evaluating environmental changes and ecosystem health because they are sensitive to disturbances in important functions of ecosystem. Studies have shown that functional groups constitute a useful method of predicting the response of ant communities to disturbances and environmental changes. This study determined the effects of lac-corn agroforest ecosystem on the diversity

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and functional groups of ground-dwelling ant communities and the role of lac-corn agroforestry ecosystem in ant diversity and ecosystem function protection. A research was conducted using pitfall traps on ground-dwelling ant communities in lac plantation, lac-corn agroforest ecosystem and cornfield in Lüchun County. A total of 11 781 individual ants were collected, belonging to 78 species, 37 genera and 7 sub-families. Lac-corn agroforest ecosystem had higher species and rare species numbers of ground-dwelling ant communities. In lac-corn agroforest ecosystem, the numbers species and rare species increased by 41% and 85%, respectively, compared with cornfield. Ant abundance in lac-corn agroforest ecosystem was significantly higher than that in lac plantation and cornfield. Ant abundance, ACE of ant in lac-corn agroforest ecosystem and lac plantation were significantly higher those of cornfield. Ant community structure of lac-corn agroforest ecosystem was similar to that of lac plantation, but dissimilar compared with cornfield. There were differences of species compositions and indicator species of the three sites. *Paratrechina vividula* and *Pheidole yeensis* were dominant species in cornfield, *Aphaenogaster beccarii* in lac plantation, and then *Monomorium chinensis*, *M. orientale*, *Crematogaster rogenhoferi*, *Polyrhachis proxima* and *Cardiocondyla wroughtonii* in lac-corn agroforest ecosystem were dominant species. *Iridomyrmex anceps* and *P. yeensis* were indicator species for cornfield, *Dolichoderus incises*, *Lepisiota xichangensis* and *M. chinensis* were indicator species for lac-corn agroforest ecosystem, and then *A. feae*, *C. ferrarii*, *Tetramorium aptum*, *A. beccarii*, and *Pseudolasius silvestrii* were indicator species for lac plantation. The proportions of different functional groups of ants in lac-corn agroforest ecosystem were in between lac plantation and cornfield. Species richness, abundance and proportions of Opportunists, Subordinate Camponotini, Cryptic Species and Climate Specialists in lac-corn agroforest ecosystem were higher than those in cornfield. Honeydew secretion by lac insects increased ant species richness and abundance in lac-corn agroforest ecosystem and lac plantation. Lac plantation and lac-corn agroforestry with more complex habitat supported more arthropods survival. Lac-corn agroforest ecosystem limited biodiversity loss caused by disturbances. It had positive effects on the protection of ground-dwelling ants and was a better sustainable development model for balancing the contradiction between environmental protection and economic development.

Keywords Land use; Lac-corn agroforest ecosystem; Ground-dwelling ant; Community composition; Biodiversity; Indicator specie; Functional group

随着人口快速增长及社会发展，人类和生态环境保护间的矛盾日益凸显，如何平衡经济发展和生物多样性保护间的矛盾一直是生态学研究的热点[1−3]，土地利用变化导致的生态后果及生态系统功能变化研究也越来越被关注[4−5]。混农林业(agroforestry)是按照经营目的及生态学原理，将农作物和林业有机组合的复合系统，能够获得最佳综合生态效益[6−7]。混农林模式能够提高土地可持续经营效果及生态效益[8]，能够支持更多的物种生存，具有较高的多样性保护价值[9−10]。已有研究多关注发展混农林对生物多样性保护的影响[11−12]，较少关注该系统内生物多样性与生态系统功能的关系研究。

紫胶虫(*Kerria* spp.)是一类具有重要经济价值的资源昆虫，其分泌的紫胶被广泛用于各行各业[13−14]。紫胶林广泛分布于我国西南地区的半干旱半湿润河谷及半山区，是当地农民的重要经济来源之一。在这些紫胶产区，紫胶生产与农业生产往往同时进行，紫胶寄主树与林下作物及周围的农田形成了紫胶混农林系统。已有研究探讨了紫胶混农林增加土壤肥力、提供薪材、保持水土[15]，以及对节肢动物类群物种丰富度的保护作用[16−19]。目前少见该模式对反映复合系统功能的节肢动物功能群的研究。

蚂蚁(Hymenoptera：Formicidae)为膜翅目昆虫，在生态系统中扮演着非常重要的角色[20−22]，是优良的指示生物[23−24]。蚂蚁功能群是依据蚂蚁生态学特点划分的具有相似功能特点的物种组合[25]，能够响应生态系统功能变化[26−27]。

本文拟调查比较紫胶玉米混农林、紫胶林和玉米旱地的地表蚂蚁群落，通过比较蚂蚁群落结构、指示物种、功能群组成及不同功能群在不同类型样地中的变化，揭示紫胶玉米混农林系统在蚂蚁多样性及生态系统功能保护中的作用，为利用紫胶混农林模式保护当地生物多样性提供一定的理论基础。

1 材料与方法

1.1 研究地概况

研究地位于云南省绿春县牛孔乡(23°02′，102°09′)海拔 900~1 150m 地段。该地域年平均温度 19.1 ℃，年均降水 1 687 mm，属山地季风气候。该地区长期从事紫胶生产，主要以紫胶纯林和紫胶混农林模式生产紫胶，紫胶混农林以紫胶玉米混作模式较为常见。紫胶林和紫胶混农林内轮流利用寄主植物放养云南紫胶虫(*Kerria yunnanensis*)，每年 10 月至次年 5 月为冬代，5 至 10 月为夏代，紫胶虫在分泌紫胶的同时也分泌大量蜜露，夏代泌胶量和蜜露量均高于冬

代。紫胶林的紫胶虫寄主植物主要为南岭黄檀(*Dalbergia balansae*)、钝叶黄檀(*Dalbergia obtusifolia*)和偏叶榕(*Ficus semicordata*)，寄主植物种植密度为825~900 株·hm^{-2}，样地郁闭度为 45%~65%，林下主要草本为紫茎泽兰(*Ageratina adenophora*)和飞机草(*Eupatorium odoratum*)；紫胶玉米混农林样地紫胶虫寄主植物为南岭黄檀，种植密度为 300~450 株·hm^{-2}，郁闭度为 25%~35%，林下种植玉米(*Zea mays*)，玉米种植密度约为 40 000 株·hm^{-2}；玉米旱地为开荒山坡地，长期种植玉米，种植密度与紫胶玉米混农林接近。紫胶玉米混农林样地和玉米旱地在 2012 年 5—10 月种植玉米，10 月至次年 4 月撂荒，种植玉米周期内会进行 1~2 次除草施肥，试验地内未喷洒过农药，撂荒期样地内草本主要为飞机草、蓝花野茼蒿(*Crassocephalum rubens*)和鬼针草(*Bidens pilosa*)等。

选取紫胶林(L)、玉米旱地(D)和紫胶玉米混农林(M)3 种类型样地，每种类型各选取 2 块面积为 150 m×200 m 地块作为试验样地，各样地间距 1 km 以上。所选取的样地坡向为南坡，坡度基本一致，各样地情况见表 1。

表 1　不同类型调查样地基本情况
Table 1　Information of different sample sites

样地 Sample site 名称 Name	代码 Code	经纬度 Longitude and latitude	海拔 Altitude (m)	郁闭度 Canopy density (%)	干扰情况 Disturbances
玉米旱地 1 Corn field 1	D1	102°07′46″, 23°02′33″	999	—	雨季栽培玉米，干扰程度较高；旱季撂荒。调查时为撂荒期，地表草本发达。
玉米旱地 2 Corn field 2	D2	102°08′12″, 23°03′08″	997	—	In rainy season, maize was cultivated with high human disturbance. In dry season, land was uncultivated. The investigation was conducted in dry season when grass grew well.
紫胶玉米混农林 1 Lac-corn agroforest ecosystem 1	M1	102°08′37″, 23°02′22″	983	39.3	乔木密度为紫胶林的 1/3，林下种植玉米，中等干扰；调查时为撂荒期，地表有草本。
紫胶玉米混农林 2 Lac-corn agroforest ecosystem 2	M2	102°09′42″, 23°02′24″	997	39.0	Tree density was 1/3 of the lac plantation, maize grew under trees. The disturbance was medium. The investigation was conducted in dry season.
紫胶林 1 Lac plantation 1	L1	102°07′45″, 23°02′56″	1021	70.0	林下草本层较发达，收获紫胶和放养紫胶虫时有人为中等干扰，调查时有轻微干扰。
紫胶林 2 Lac plantation 2	L2	102°08′09″, 23°02′02″	1065	52.7	Grass layer under forest grew well. Disturbance was medium.

1.2　调查方法

于 2012 年 10 月下旬和 2013 年 4 月下旬进行 2 次调查，使用陷阱法调查地表蚂蚁群落。在每块样地内设置 15 个陷阱(陷阱直径 60 mm，高度 90 mm；5×3 网格状分布，每个样地内的陷阱设置顺序一致)，陷阱间距 10 m，每个陷阱内倒入 50 mL 乙二醇(50%)作为陷阱溶液，放置 48 h 后收集陷阱内的蚂蚁，保存于 75%酒精的离心管中，带回实验室根据相关资料将蚂蚁鉴定到种，不能鉴定到种的以形态种对待[21−22]。

1.3　分析方法

将两次调查的数据合并后分析，采用 6 级计分制对蚂蚁多度数据进行转换(1：1 头；2：2~5 头；3：6~10 头；4：11~20 头；5：21~50 头；6：>50 头，文中多度均为转换后多度)，以防止一些种类的蚂蚁在少数样本中被大量计数[28−29]。

1)物种组成：统计各样地内蚂蚁物种数及物种个体数，以每个物种的多度占样地内多度总和百分率确定优势种和稀有种：>10%为优势种，1%~10%为常见种，<1%为稀有种[22]。使用 R 语言的 iNEXT 软件包绘制基于样本数的物种稀疏与预测曲线[30]。

2)多样性：按照取样顺序每 5 个陷阱数据作为一个样本计算各样地地表蚂蚁群落多度、物种丰富度 *S* 及 ACE 估计值[31−32]。通过 EstimateS 软件计算以上多样性指数[33]，运用 SPSS 18 中的单因素方差分析(One-way ANOVA)中的 LSD 方法对 3 类样地地表蚂蚁多度、物种丰富度 *S* 和 ACE 估计值进行多重比较，比较前物种丰富度 *S* 及 ACE 估计值进行对数转换，检验方差齐同。

3)群落结构相似性：利用统计软件 R 语言中的非度量多维调节分析(NMDS, non-metric multidimensional scaling)方法比较紫胶林、玉米旱地和紫胶玉米混农林的地表蚂蚁群落结构相似性。使用 PRIMER v6 中的主坐标(PCO)分析方法，筛选出与样地相关性大于 0.9(Pearson 系数)的物种，并绘制 PCO 排序图[34−35]。

4)指示物种：利用统计软件 R 语言中的 labdsv 软件包计算各物种的 IndVal 值[36]，参考相关研究以 IndVal 值≥0.7 作为标准确定指示物种[37]。

5)功能群：依据 Andersen 和 Brown 的划分方法[25,38](考虑蚂蚁竞争关系、生境要求和行为优势等)，在属

级水平上划分 7 个功能群：优势臭蚁亚科(Dominant Dolichoderinae, DD)、从属弓背蚁族(Subordinate Camponotini, SC)、气候特化种(Climate Specialists, CS)、隐蔽物种(Cryptic Species, C)、广义切叶蚁亚科(Generalized Myrmicinae, GM)、机会主义者(Opportunists, O)和专业捕食者(Specialist Predators, SP)。使用蚂蚁多度计算不同功能群在各样地的比例，比较不同样地功能群组成差异。按每 5 个陷阱为一组，分别统计每组中各功能群的蚂蚁物种数和多度，使用 SPSS 18.0 中的单因素方差分析比较每个功能群蚂蚁物种数和多度在玉米旱地、紫胶林和紫胶玉米混农林中的差异。

2 结果与分析

2.1 紫胶混农模式对地表蚂蚁物种组成及多度的影响

共采集蚂蚁 11 781 头，隶属于 7 亚科、37 属、78 种。在玉米旱地中共采集蚂蚁 4 457 头，隶属于 4 亚科、22 属、41 种；在紫胶玉米混农林样地共采集蚂蚁 4 430 头，隶属于 7 亚科、30 属、58 种；在紫胶林共采集蚂蚁 2 894 头，隶属于 6 亚科、30 属、60 种。

在常见种和优势种物种数量方面，紫胶玉米混农林模式与其他模式差别不大，但是紫胶玉米混农林稀有种最多，旱地最少(表 2)。紫胶玉米混农林和紫胶林有利于稀有物种保护，为种群数量较小的蚂蚁提供生存空间。

表 2 各调查样地地表蚂蚁物种组成情况

Table 2 Composition of ground-dwelling ant species of different sample sites

	玉米旱地 Corn field	紫胶玉米混农林 Lac-corn agroforest ecosystem	紫胶林 Lac plantation
优势种数 Dominant species number	1	1	0
常见种数 Common species number	20	20	25
稀有种数 Rare species number	20	37	35
合计 Total	41	58	60

各样地物种累积曲线上升后趋于平缓，抽样较充分，通过曲线预测部分可以看出，紫胶林和紫胶玉米混农林的蚂蚁物种数明显高于玉米旱地(图 1)。

2.2 紫胶混农模式对地表蚂蚁多样性的影响

与玉米旱地相比，紫胶玉米混农林和紫胶林具有更高的地表蚂蚁多样性水平。3 种类型样地地表蚂蚁多度有显著差异[$F_{(2,\ 15)}$=5.406, P=0.017]，其中紫胶玉米混农林样地显著高于紫胶林和玉米旱地，

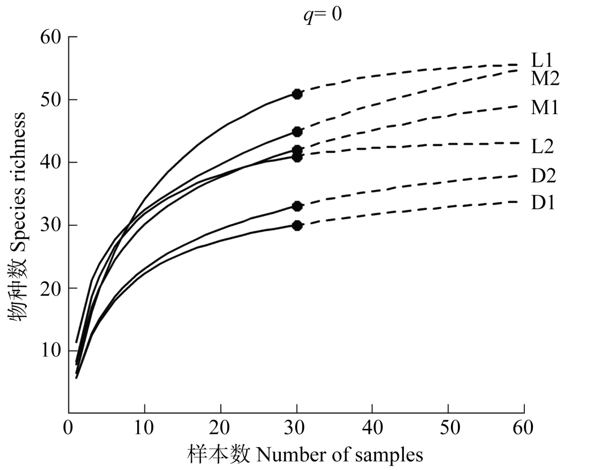

图 1 不同类型样地地表蚂蚁基于样本数的物种稀疏和预测曲线

Fig. 1 Rare species number and extrapolation curves of ant communities of different sites based on number of samples

D: 玉米旱地; L: 紫胶林; M: 紫胶玉米混农林; 下同。图中 q 为 Hill 值，q=0 时表示基于全部物种预测；实线部分表示物种实际观测值，虚线部分为基于样本数的物种多度预测。D: corn field; L: lac plantation; M: lac-corn agroforest ecosystem. The same below. q is Hill number, q=0 means investigator using diversity of all species. Solid lines are observed values, dotted lines are estimated values based on samples number.

玉米旱地地表蚂蚁多度最低。3 种类型样地地表蚂蚁物种丰富度 S 值有显著差异[$F_{(2,\ 15)}$=32.535, P<0.01]，紫胶玉米混农林和紫胶林地表蚂蚁物种丰富度 S 值无显著差异，但均显著高于玉米旱地。3 种类型样地地表蚂蚁 ACE 估计值有显著差异[$F_{(2,\ 15)}$=4.456, P=0.030]，紫胶玉米混农林和紫胶林地表蚂蚁 ACE 估计值无显著差异，但二者均显著高于玉米旱地(表 3)。

表 3 不同类型样地地表蚂蚁多样性比较

Table 3 Diversity comparison of ground-dwelling ant among different sample sites

样地 Sample site	多度 Abundance	物种丰富度 Species richness	ACE
玉米地 Corn field	133.67±10.66b	3.13±0.03b	3.35±0.08b
紫胶玉米混农林 Lac-corn agroforest ecosystem	221.17±26.09a	3.43±0.04a	3.64±0.10a
紫胶林 Lac plantation	158.67±18.25b	3.50±0.03a	3.61±0.04a

表中物种丰富度和 ACE 估计值进行了对数转换，同列不同字母表示 P<0.05 水平上差异显著。Data of species richness and ACE are logarithmically transformed. Data with different letters are significantly different at 0.05 level.

2.3 不同类型样地地表蚂蚁群落结构的相似性

紫胶林和紫胶玉米混农林具有相似的地表蚂蚁群落结构，二者与玉米旱地明显不相似(图 2)。

主坐标分析结果与 NMDS 排序结果一致，紫胶林和紫胶玉米混农林蚂蚁群落结构相似，二者与玉米旱地不相似。由物种组成来看，亮立毛蚁(*Paratrechina*

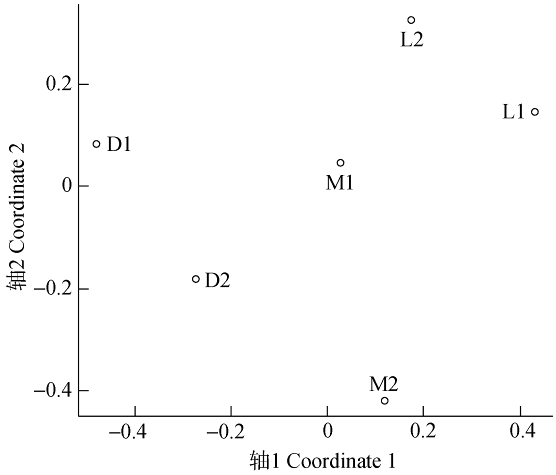

图 2　不同类型样地基于蚂蚁有无数据的 **NMDS** 排序

Fig. 2　NMDS ordinations for ant communities based on presence/absence of ground-dwelling ant in different sample sites

vividula)和伊大头蚁(*Pheidole yeensis*)与玉米旱地具有较高的相关性；贝卡盘腹蚁(*Aphaenogaster beccarii*)与紫胶林有较高的相关性，中华小家蚁(*Monomorium chinensis*)、东方小家蚁(*M. orientale*)、黑褐举腹蚁(*Crematogaster rogenhoferi*)、邻居多刺蚁(*Polyrhachis proxima*)和罗氏心结蚁(*Cardiocondyla wroughtonii*)与紫胶玉米混农林及紫胶林具有较高的相关性(图 3)。

2.4　不同类型样地蚂蚁指示物种

3 种类型样地地表蚂蚁指示物种有差异(表 4)。玉米旱地有 2 种指示种，分别为扁平虹臭蚁(*Iridomyrmex anceps*)和伊大头蚁；紫胶玉米混农林有 3 种指示种，分别为凹头臭蚁(*Dolichoderus incisus*)、西昌刺结蚁(*Lepisiota xichangensis*)和中华小家蚁；紫胶林有 5 种指示种，分别为费氏盘腹蚁(*Aphaenogaster feae*)、立毛举腹蚁(*Crematogaster ferrarii*)、阿普特铺道蚁(*Tetramorium aptum*)、贝卡盘腹蚁和西氏拟毛蚁(*Pseudolasius silvestrii*)，其中举腹蚁属和盘腹蚁属蚂蚁多喜食蜜露。

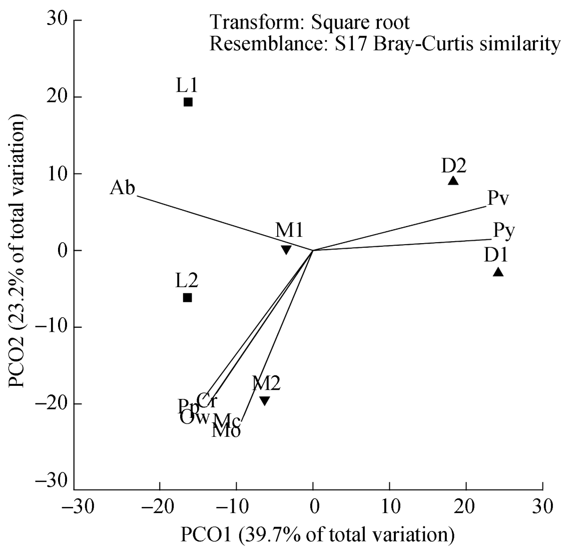

图 **3**　不同类型样地地表蚂蚁群落结构主坐标分析

Fig. 3　PCO analysis of community structures of ground-dwelling ant in different sample sites

Ab：贝卡盘腹蚁；Cr：黑褐举腹蚁；Cw：罗氏心结蚁；Mc：中华小家蚁；Mo：东方小家蚁；Py：伊大头蚁；Pp：邻居多刺蚁；Pv：亮立毛蚁。Ab: *Aphaenogaster beccarii*; Cr: *Crematogaster rogenhoferi*; Cw: *Cardiocondyla wroughtonii*; Mc: *Monomorium chinensis*; Mo: *M. orientale*; Py: *Pheidole yeensis*; Pp: *Polyrhachis proxima*; Pv: *Paratrechina vividula*.

表 **4**　不同类型样地基于评分后多度的地表蚂蚁指示物种分析

Table 4　Indicator species analysis of ground-dwelling ant communities based on ant abundance after scales in different sample sites

样地 Site	物种名 Species	指示值 IndVal	*P*
玉米旱地 Corn field	扁平虹臭蚁 *Iridomyrmex anceps*	1.000 0	0.030
	伊大头蚁 *Pheidole yeensis*	0.984 8	0.034
紫胶玉米混农林 Lac-corn agroforest ecosystem	凹头臭蚁 *Dolichoderus incisus*	1.000 0	0.001
	西昌刺结蚁 *Lepisiota xichangensis*	0.909 1	0.001
	中华小家蚁 *Monomorium chinensis*	0.703 4	0.043
紫胶林 Lac plantation	费氏盘腹蚁 *Aphaenogaster feae*	1.000 0	0.037
	立毛举腹蚁 *Crematogaster ferrarii*	0.929 8	0.001
	阿普特铺道蚁 *Tetramorium aptum*	0.923 1	0.001
	贝卡盘腹蚁 *Aphaenogaster beccarii*	0.846 2	0.001
	西氏拟毛蚁 *Pseudolasius silvestrii*	0.705 9	0.001

指示值计算公式为：$IndVal_{ij}=A_{ij}\times B_{ij}$，$A_{ij}$ 表示物种 i 在样地 j 中的特异性，B_{ij} 表示物种 i 在样地 j 中的保真度。P 是在 1 000 次重复基础上得到的；仅列出具有统计学差异的指示物种。$IndVal_{ij}=A_{ij}\times B_{ij}$, in which A_{ij} is the proportion of species i in sample site j, B_{ij} is the proportion of the number of abundance of species i in sample site j; P is based on 1 000 permutations. Only statistically significant indicator species is presented.

2.5　不同类型样地地表蚂蚁功能群分析

土地利用方式直接影响了地表蚂蚁功能群的组成，不同蚂蚁功能群对土地利用的响应有差异(图 4)。3 类样地地表蚂蚁功能群组成中，广义切叶蚁亚科所占比例均超过 50%，其中玉米旱地广义切叶蚁亚科的比例达 70%，高于紫胶林和紫胶玉米混农林。

紫胶林机会主义者和从属弓背蚁族的比例高于紫胶玉米混农林和玉米旱地，玉米旱地最低。紫胶玉米混农林隐蔽物种的比例与玉米旱地差异不大，二者明显低于紫胶林。紫胶玉米混农林气候特化种和专业捕食者的比例高于玉米旱地和紫胶林，玉米旱地最低。优势臭蚁亚科仅出现在玉米旱地。玉米旱地有利于广义切叶蚁亚科和优势臭蚁亚科类群，紫胶林有利于机会主义者、从属弓背蚁族和隐蔽物种类群，紫胶玉米混农林除优势臭蚁亚科外，其余功能群的比例趋向于介于玉米旱地和紫胶林之间(图 4)。

不同蚂蚁功能群在玉米旱地、紫胶林和紫胶玉米混农林的物种数和多度上有差异，整体上来看，紫胶林和紫胶玉米混农林的蚂蚁物种数和多度均显著高于玉米旱地，其中，气候特化种、机会主义者和从属弓背蚁族蚂蚁多度和物种数明显低于紫胶林和紫胶玉米混农林；紫胶林与紫胶玉米混农林大部分功能群的蚂蚁多度和物种数较为接近。隐蔽物种的蚂蚁多度和物种数在玉米旱地、紫胶林和紫胶玉米混农林中无显著差异。紫胶玉米混农林气候特化种的蚂蚁多度显著高于紫胶林和玉米旱地，玉米旱地最低；但该功能群的蚂蚁物种数在 3 类样地中无显著差异。紫胶玉米混农林广义切叶蚁亚科的蚂蚁多度显著高于紫胶林和玉米旱地，同样，该功能群物种数在 3 类样地中无显著差异。紫胶林机会主义者的蚂蚁多度和物种数显著高于玉米旱地，紫胶玉米混农林仅物种数显著高于玉米旱地。紫胶林和紫胶玉米混农林从属弓背蚁族的蚂蚁多度显著高于玉米旱地，多度在 3 类样地中无显著差异。紫胶玉米混农林专业捕食者的多度显著高于紫胶林和玉米旱地，紫胶林专业捕食者的蚂蚁物种数显著高于玉米旱地(表 5)。

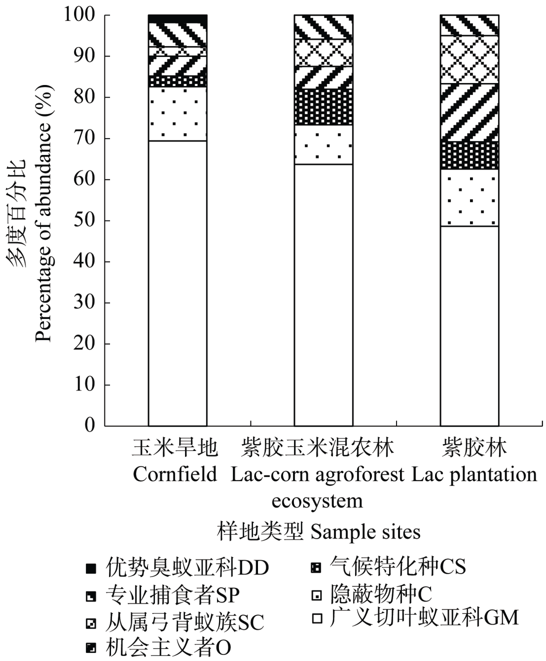

图 4 不同类型样地地表蚂蚁功能群组成

Fig. 4 Functional groups composition of ground-dwelling ant in different sample sites

DD: Dominant Dolichoderinae; SC: Subordinate Camponotini; CS: Climate Specialists; C: Cryptic Species; GM: Generalized Myrmicinae; O: Opportunists; SP: Specialist Predators.

表 5 不同类型样地不同功能群蚂蚁多度及物种数单因素方差分析

Table 5 ANOVA analysis of ant abundance and species number of different functional groups in different sample sites

功能群 Functional group		玉米旱地 Corn field	紫胶林 Lac plantation	紫胶玉米混农林 Lac-corn agroforest ecosystem	*F*	*P*
隐蔽物种 Cryptic Species	多度 Abundance	4.66±0.35	4.57±0.34	4.99±0.48	0.304	0.742
	物种数 Species richness	1.23±0.09	1.54±0.13	1.50±0.13	2.208	0.166
气候特化种 Climate Specialists	多度 Abundance	1.84±0.35c	3.18±0.38b	4.59±0.14a	20.050	<0.010**
	物种数 Species richness	0.37±0.23	0.98±0.35	1.26±0.13	3.207	0.069
广义切叶蚁亚科 Generalized Myrmicinae	多度 Abundance	8.34±0.33b	7.56±0.76b	10.38±0.58a	6.263	0.011*
	物种数 Species richness	2.16±0.09	2.19±0.04	2.26±0.05	0.747	0.491
机会主义者 Opportunists	多度 Abundance	3.44±0.25b	5.68±0.46a	4.71±0.51ab	7.014	0.007**
	物种数 Species richness	1.48±0.16b	2.16±0.09a	1.86±0.07a	9.625	0.002**
从属弓背蚁族 Subordinate Camponotin	多度 Abundance	2.94±0.37	4.13±0.62	4.12±0.22	2.185	0.149
	物种数 Species richness	0.69±0b	1.18±0.17a	1.36±0.09a	7.812	0.005**
专业捕食者 Specialist Predators	多度 Abundance	3.67±0.28b	3.72±0.19b	4.86±0.18a	9.219	0.002**
	物种数 Species richness	1.17±0.11b	1.46±0.05a	1.39±0ab	4.455	0.030*

表中多度数据为评分后数据，方差分析前多度进行平方根转换、物种数进行对数转换，并进行方差齐性检验。优势臭蚁亚科仅 1 属 1 种，未列入比较。表中同行不同字母表示不同调查样地在 P=0.05 水平差异显著。Abundance data are scaled square-root-transformed. Data of species richness are logarithmically transformed. Dominant Dolichoderinae is not included because only one species in this group. Different letters in one row mean significant difference among sample sites at 0.05 level.

3 讨论

结构复杂多样及食物资源丰富的生态系统更加有利于蚂蚁多样性保护[39–44]。本研究中，紫胶林和紫胶玉米混农林地表蚂蚁物种数比玉米旱地分别高46%和 41%; 地表蚂蚁出现频次分别高 23%和 63%。原因之一是紫胶虫分泌的蜜露显著增加了林地内地表蚂蚁的物种数和频次。虽然紫胶玉米混农林紫胶虫的数量要低于紫胶林，但其地表蚂蚁的多度水平与紫胶林接近、而物种数则超过了紫胶林。另外，在植物组成上，紫胶林和紫胶玉米混农林栖境比玉米旱地相对复杂，同时紫胶林和紫胶玉米混农林中还有紫胶虫的蜜露喷射到植物、地表等不同栖境，为生活在不同层次的蚂蚁提供了充足的食物资源，使得紫胶林和紫胶玉米混农林具有更高的栖境异质性，提高了蚂蚁的种群数量和出现频次，结果与咖啡园蚂蚁群落研究结论一致[45]。地表蚂蚁群落多样性分析结果显示，紫胶玉米混农林地表蚂蚁多样性整体高于紫胶林(图 2)，可能是紫胶玉米混农林乔木的密度和郁闭度低于紫胶林，林下作物及林下杂草上生活有更多的节肢动物，蚂蚁可以获得额外的蛋白质食物资源，间接提高了的蚂蚁多样性。紫胶林和紫胶玉米混农林对小种群蚂蚁类群的影响尤为显著，在不影响常见蚂蚁类群的情况下(表 2)，增加了稀有物种蚂蚁的多样性，具有较高的蚂蚁多样性保护功能和价值。

随着土地利用强度的增加，多样性呈下降趋势[46]。紫胶玉米混农林和玉米旱地均在相同时间种植玉米并有类似的管理强度，而紫胶林只是在每年固定的时间段内采收紫胶和放养胶虫，和紫胶纯林相比，紫胶玉米混农林的利用强度相对较高，但其地表蚂蚁群落结构接近于紫胶纯林，与玉米旱地的相似性较低，证明蜜露显著影响了地表蚂蚁群落结构，在一定程度上减缓了干扰导致的蚂蚁多样性降低。由物种组成及指示物种来看，伊大头蚁、亮立毛蚁和扁平虹臭蚁与玉米旱地明显相关，这些物种喜欢开放、干旱、有干扰的栖境[26]，说明玉米旱地的利用强度较高，干扰较大; 紫胶玉米混农林和紫胶林中则多为喜食蜜露的种类，如盘腹蚁属和举腹蚁属仅出现在紫胶玉米混农林和紫胶林中，说明紫胶玉米混农林模式对喜食蜜露的蚂蚁具有明显的保护作用。

功能群的划分可以使研究系统复杂性大大降低，弱化个体的个别作用，能更好地反映出生物与环境的相互关系[47–49]。本研究中，地表蚂蚁功能群对土地利用和干扰表现出了明显的响应作用。广义切叶蚁亚科中的大头蚁属、小家蚁属和举腹蚁属是广泛分布于温暖栖境中的优势类群，在非干热环境中代替优势臭蚁亚科成为优势蚂蚁类群[50]，优势臭蚁亚科和大头蚁属常生活在开放、有干扰的栖境中，说明 3 种类型的样地均受到一定程度干扰，而玉米旱地中大头蚁属比例达 76.7%，远高于紫胶玉米混农林(41.3%)和紫胶林(26.7%)，另外，优势臭蚁亚科仅出现在玉米旱地，说明玉米旱地的干扰程度及环境压力要明显高于紫胶玉米混农林和紫胶林。隐蔽物种多在土壤和枯落物中觅食，与栖境条件及干扰程度关联性最高[48]，3 种类型样地中，隐蔽物种在紫胶林中比例最高，说明紫胶林干扰最少。紫胶林和紫胶玉米混农林机会主义者、从属弓背蚁族、气候特化种的比例明显增加，具有更多的物种数及多度，可能与紫胶虫分泌的蜜露有关。机会主义者和从属弓背蚁族广泛分布于各种栖境，但竞争能力较弱[48,51]，紫胶林和紫胶玉米混农林中丰富的蜜露资源增加了它们获得食物资源的机会，提高了蚂蚁种群数量，显著提高了铺道蚁属、盘腹蚁属、酸臭蚁属和弓背蚁属等类群的多度，对保护蚂蚁多样性均有一定意义。气候特化种蚂蚁种群发展依赖特定的环境条件及植物的可利用程度[52]，紫胶玉米混农林和紫胶林支持较多的气候特化种生存，说明这两种栖境条件要优于玉米旱地。此外，专业捕食者由中到大型蚂蚁组成，种群数量较低，食性特化，与其他蚂蚁的相互作用不大[48]，该类群蚂蚁通常捕食其它节肢动物[51]，紫胶玉米混农林专业捕食者的比例高于紫胶林和玉米旱地，显示出紫胶玉米混农林系统栖境异质性更高，能够容纳更多的节肢动物，间接增加了专业捕食者的种群数量。

紫胶玉米混农林对地表蚂蚁群落具有较好的保护作用，特别是能够增加种群较小、竞争能力较弱、对栖境要求高的蚂蚁类群的种群数量，从而提高蚂蚁多样性; 能增加蚂蚁功能群组成及比例，是保持生态和经济效益可持续发展的较好模式。蚂蚁功能群作为生物指示对栖境变化响应十分敏感。

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